errors found in the prepublication version and the corrections.

We realize that only a small fraction of the public will take time to scrutinize our report, but we hope that those who do will use the evidence in the report to elevate the level of public conversation about GE crops, not simplify it.

COMPETING FINANCIAL INTERESTS
The authors declare competing financial interests: details are available in the online version of the paper.

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1. Giddings, L.V. & Miller, H. *Nat. Biotechnol.* **34**, 1226–1228 (2016).
2. The National Academies. *Genetically Engineered Crops: Experiences and Prospects* (National Academies Press, 2016).
3. Iles, Alastair *et al.* https://www.panna.org/sites/default/files/NRC%20Nominations%20Letter.pdf (2014).
4. Anonymous. http://academicsreview.org/2012/09/letter-to-the-national-academy-of-sciences/ *Academics Rev.* (2012).
5. Anonymous. http://www.gallup.com/poll/6424/nutrition-food.aspx?version=print (Gallup, 2016).
6. US Department of Agriculture. *Crop Production Historical Track Records* http://usda.mannlib.cornell.edu/usda/current/htrcp/htrcp-04–14–2016.pdf (USDA, Washington, DC, 2016).
7. Schiek, B. *et al. Int. J. Biotechnol.* **14**, 112–131 (2016).
8. National Research Council. *Understanding Risk: Informing Decisions in a Democratic Society* (National Academies Press, Washington, DC, USA).
9. Glickman, D. in *Environmental Politics Casebook: Genetically Modified Foods* (ed. Miller, N.) 45–58 (Lewis Publishers, Boca Raton, FL, 1999).
10. Funk, C. & Kennedy, B. *The New Food Fights: US Public Divides Over Food Science* (Pew Initiative, Washington, DC, 2016).

National Academies report has broad support

To the Editor:

Last December, the US National Academy of Sciences (NAS) Board of Agriculture and Natural Resources convened a Forum of Scientific Society Leaders on Genetically-Engineered Crops: Experiences and Prospects (http://dels.nas.edu/Upcoming-Event/Forum-Scientific-Society-Leaders/AUTO-5-80-52-G?bname=banr). Invited participants were representatives of professional scientific societies or other organizations with an interest in the science behind the agronomic, health, environmental, and socioeconomic implications of genetically engineered (GE) crops. They were asked to comment on the scientific validity of the findings and recommendations of the NAS GE crops report released in May 2016 (ref. 1) and to suggest future directions. The participants represented 17 major scientific societies and independent research organizations and thousands of scholars working on GE-crop-related research. Forum participants expressed general support for the majority of the report findings, offering a nuanced and appreciative view of its contents.

This contrasts markedly with the sharp critique of the same NAS report by L. Val Giddings and Henry Miller[2] published in your December issue. After reading their Correspondence, we wish to share our assessment of the NAS report with your readers. We represent a subset of Forum participants. Although our views have not been formally endorsed by all of our respective scientific societies, we represent a wealth of diverse scientific expertise and experience.

As a whole, our professional assessment is that the NAS report offers an extensive and authoritative review of peer-reviewed scientific literature on a wide range of topics related to the agronomic performance of GE crops, the social, economic, political, health, safety, and regulatory context that guides the trajectory of GE technological innovation, and the costs and benefits of these technologies. We broadly agree with key conclusions of the NAS report that:

- "…no differences have been found that implicate a higher risk to human health safety from these GE foods than from their non-GE counterparts" (p. 19);
- GE crops "have generally had favorable economic outcomes for producers who have adopted these crops, but there is high heterogeneity in outcomes" (p. 20);
- the ability of GE crops "to benefit intended stakeholders will depend on the social and economic contexts in which the technology is developed and diffused" (p. 22); and finally,
- the scientific evidence suggests that "it is the product, not the process, that should be regulated" (p. 26).

The NAS report notes that most of the extant peer-reviewed scientific research is focused on resistance to herbicides (mainly glyphosate) and resistance to insect pests (via *Bacillus-thuringiensis*-derived Cry proteins). We concur with the committee's conclusion that GE crops have been adopted on millions of hectares without the emergence of scientific evidence of serious health and environmental problems that were expected by early critics of the technology. At the same time, we applaud the report for not overstating what is known about potential short- and long-term health, environmental, and socioeconomic implications of emerging GE traits.

Giddings and Miller criticize the qualified language of the report because they were hoping for the NAS to "overtly back GE crops." But in our view, the more nuanced phrasing in the NAS report represents a balanced and objective reading of the peer-reviewed evidence.

The NAS committee reported that, on a national scale, rates of yield increases in maize, cotton, and soybean were the same before the advent of GE crops as afterward, concluding

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that there was an absence of a "signature of GE technology on the rate of yield increase." This finding, criticized by Giddings and Miller, has received more attention than the more positive findings about yield in other sections of the report.

In reality, the report includes detailed discussions of the evidence for yield benefits (and other non-yield benefits appreciated by farmers), both in developed countries and in developing countries, where yield benefits have sometimes been quite substantial. Although there are methodological challenges in comparing GE and non-GE crop yields, where yield gains were observed, they have been mostly attributable to closing the gap between potential and actual yield by limiting losses from weeds, insect pests, and disease. Thus, where biotic pressure on crops is low, yield advantages of most present-day GE crops would be expected to be minimal. Where pressure is high, one would expect yield benefits. Unlike most current GE crops, future GE crop traits offer the potential to increase genetic yield potential (e.g., by increasing nutrient-use efficiency or photosynthesis). However, research on such outcomes awaits the advent of commercially viable crop varieties possessing such traits.

Giddings and Miller also expressed concern that the NAS report failed to provide direction to policymakers, specifically with respect to a perceived "discriminatory, onerous" regulatory system. The report provides an extensive review of differences in approaches to GE regulation across different countries, and a summary of scientific studies designed to quantify the costs and benefits associated with regulatory delays. The NAS report is quite clear that scientific evidence would support a different approach in which "it is the product, not the process, that should be regulated" (p. 26). We note that the committee's core task was to conduct a broad review of the scientific evidence about purported negative impacts and benefits associated with GE crops, and to review the scientific foundation of current safety assessment processes. The committee was not asked to give specific guidance to regulatory agencies.

Giddings and Miller challenged the notion presented in Chapter 5 that omics techniques may provide newer methods for assessing substantial equivalence through "broad, non-targeted assessment of thousands of plant characteristics" and that "These methods are more likely to detect changes in a GE crop than the current regulatory approaches" (p. 200). Their criticism was also shared by several Forum participants, who pointed out that the NAS report provided very little supportive evidence for the position that omics can be used to advance the current regulatory approach to GE crops. It is worth noting that the report stated that "differences in composition found by using 'omics methods do not, on their own, indicate a safety problem" (p. 201). Although the practical value of non-targeted 'omics techniques for food safety evaluations has not been demonstrated, they can be useful for discovery research[3]. This conclusion is consistent with the NAS report finding in Chapter 7 that "Application of 'omics technologies has the potential to reveal the extent of modifications of the genome, the transcriptome, the epigenome, the proteome, and the metabolome that are attributable to conventional breeding, somaclonal variation, and genetic engineering" (p. 395). In reality, the ultimate conclusions reached in the NAS report are not much different from those of Giddings and Miller, who wrote, "The problem with this ['omics] is that it is completely unclear what such comparisons would mean; we don't know enough to correlate omics patterns to traits, let alone to hazard or risk."

Finally, Giddings and Miller are critical of how the NAS report encourages greater public dialog regarding GE crop policy decisions. They note that science is not a democracy. We agree. However, we also believe that technology governance cannot be delegated exclusively to the realm of the natural sciences. Risk management and public policy decisions about regulating GE crops cannot be based on science alone because these decisions typically involve tradeoffs across competing and sometimes uncertain objectives, interests and values. Different cultures and governing bodies might reasonably use the same scientific evidence to reach different recommendations about the nature and degree of regulatory oversight. Issues related to consumer freedom of choice and challenges associated with the co-existence of GE, non-GE, and organic production are common sources of disagreement. The NAS report makes these points clearly and grounds them in the extensive scientific literature on this topic.

Importantly, the recommendation for greater public engagement and transparency in the NAS report is buttressed by numerous studies on the growing lack of trust in science among the general public. The aim of public engagement should not be to educate an ill-informed public so they 'discover the science' and agree that GE crops should be widely adopted (the so-called information-deficit model). Rather, successful public engagement requires a multi-directional flow of knowledge and a broad dialog about both scientific facts and public values that necessarily underlie policy decisions about GE products.

Although we respect their arguments that regulatory systems could be improved, Giddings and Miller did not accurately represent the literature about previous efforts to facilitate public input into policy making for GE crops. They cite the 2008 National Citizens Technology Forum (NCTF) as an example of failed public engagement about agricultural biotech. In fact, the NCTF was about nanotechnology and human enhancement. They also cite a study about a public engagement exercise related to GE crops in the UK. In both cases, although the cited studies reviewed strengths and weaknesses of approaches to citizen engagement, those studies did not conclude that the processes were a failure, as suggested by Giddings and Miller.

More broadly, we want to draw attention to the fact that, in an attempt to ensure the NAS committee addressed the full breadth and content of public debates about GE crops, it made an appropriate effort to solicit input from a wide range of advocates and opponents of GE crops. The NAS report and supporting website materials systematically addressed public comments with appropriate references to published scientific literature. At the Forum of Scientific Society Leaders, many participants agreed that more public science communication, not less, would be key to the future of acceptance of GE technology by consumers.

Overall, the NAS report provides an updated and authoritative summary of scientific evidence related to the agronomic, health, environmental, and socioeconomic effects of GE crops. The report addresses many criticisms of GE crops, but appropriately notes that the field is rapidly changing. Future GE crop traits are likely to offer opportunities and risks that are different from the current mix. As a result, rather than succumbing to 'political correctness', the NAS report refrains from blanket statements that all GE crops are inherently risky or safe. Rather, the report describes that GE technology *per se* raises few risks not inherent to other modes of crop improvement. Accordingly, the report points to the need for public dialog and regulatory review processes to pay more attention to the genetic traits resulting from new technologies, rather than the processes by which traits are created.

AUTHOR CONTRIBUTIONS

P.V., D.J.-S., and M.Holsapple contributed equally to the development of the manuscript. The remaining authors

(arranged alphabetically by surname) reviewed and commented on earlier drafts of the manuscript.

DISCLAIMER

To illustrate the breadth of representation from professional scientific societies, some authors have listed their society affiliations in addition to their professional positions. However, all the views are those of the authors as individuals, and their positions do not necessarily reflect the official views of the professional scientific societies they represented at the Forum.

COMPETING FINANCIAL INTERESTS

The authors declare no competing financial interests.

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1. The National Academies. *Genetically Engineered Crops: Experiences and Prospects* (National Academies Press, 2016).
2. Giddings, L.V. & Miller, H. *Nat. Biotechnol.* **34**, 1226–1228 (2016).
3. Chassy, B.M. *Regul. Toxicol. Pharmacol.* **58** Suppl, S62–S70 (2010).

L Val Giddings & Henry Miller reply: Because the Gould *et al.*[1] and Vincelli *et al.*[2] letters have extensive overlap, we respond to them together.

We do not dispute that many of the salient conclusions of the May US National Academy of Sciences (NAS) report were correct; but most were substantially equivalent to the crisper and more useful formulations in the NAS and US National Research Council (NRC) analyses of 1987 and 1989, respectively. For example, from the NRC report:

"Crops modified by molecular and cellular methods should pose risks no different from those modified by classical genetic methods for similar traits. As the molecular methods are more specific, users of these methods will be more certain about the traits they introduce into the plants…The types of modifications that have been seen or anticipated with molecular techniques are similar to those that have been produced with classical techniques. No new or inherently different hazards are associated with the molecular techniques. Therefore, any oversight of field tests should be based on the plant's phenotype and genotype and not on how it was produced"[3].

That was written almost three decades ago and since then has been reaffirmed in countless contexts, in the United States, Europe, and elsewhere. How many times must this wheel be reinvented?

Likewise, we do not dispute that the NAS panel sought a wide spectrum of views, some of which were extreme. But the objective of the report was not to survey every opinion under the sun; it was to arrive at correct and informative answers[4]. The panel should have paid more heed to the advice of biologist Don Kennedy, member of the Academy, president emeritus of Stanford University, and former head of the US Food and Drug Administration (FDA), who chided those "who give up the difficult task of finding out where the weight of scientific evidence lies, and instead attach equal value to each side in an effort to approximate fairness. In this way, extraordinary opinions…are promoted to a form of respectability that approaches equal status"[5].

Vincelli *et al.*[2] note that they "concur with the committee's conclusion that genetically engineered (GE) crops have been adopted on millions of hectares without emergence of scientific evidence of serious health and environmental problems that were expected by early critics of the technology." So do we. But we note further the lack not only of evidence of harm but also of credible hypotheses of potential novel risk. In such circumstances, how can existing, let alone additional unwarranted regulation (e.g., directed at genome-editing technologies) possibly be justified? As the US Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) stated in a recent proposal for further regulation that lacked any foundation in science, logic, or experience:

"…APHIS has issued more than 18,000 authorizations for the environmental release of GE organisms in multiple sites, primarily for research and development of improved crop varieties for agriculture. Additionally, APHIS has issued more than 12,000 authorizations for the importation of GE organisms, and nearly 12,000 authorizations for the interstate movement of GE organisms…APHIS has granted 124 determinations of nonregulated status…The Agency's evaluations to date have provided evidence that most genetic engineering techniques, even those that use a plant pest as a vector, vector agent, or donor, do not result in a GE organism that presents a plant pest risk"[6].

The agency thereby indicts not only its own current regulations but also its proposed revisions, which utterly fail to incorporate the obvious lessons of its own (and others') experience. The NAS had the opportunity to make this clear. It failed to do so.

Vincelli *et al.* also note that uncertainties remain about possible "socioeconomic implications of emerging GE traits," a gratuitous truism. The horseless carriage and the transistor augured profoundly negative socioeconomic impacts for buggy whip and vacuum tube manufacturers, respectively. After finding them to meet the relevant safety criteria, should regulators tasked with ensuring their safety have prohibited their development based on socioeconomic implications for manufacturers of buggy whip and vacuum tubes? Should citrus genetically engineered to grow in Canada be proscribed on the grounds that it would have 'socioeconomic implications' for citrus farmers in Spain, the United States, and Brazil?

Rent seeking by special interests is a perversion of—not a justification for—government regulation. None of the legal authorities applied by regulators under the Coordinated Framework legitimizes it. But given the profound positive economic, humanitarian, and environmental impacts of molecular genetic engineering to date, the intelligent incorporation of socioeconomic considerations would dictate not the

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